Educating for a Carbon Neutral Future: A Danish Perspective in a Global World

BIM and Parametric methodologies are not just tools to optimize the design process, but they can also be used pedagogical tools creating links between the design of the building and an understanding of which parameters in the design affects the performance of the building and in which way.

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INTRODUCTION

The current focus on carbon neutrality in architecture calls for new workflows or procedures. In a Danish context, focus has been on energy efficiency in buildings since the oil crisis in the seventies. Within the past ten years, the demands in the energy frame has increased significantly with the 2020 demands calling for an energy use of 20 kWh/m2 per year.[1] Furthermore, pilot projects ranging from self-sufficient architecture by grass root movements to experiments with passive and smart houses developed in collaboration between leading companies in the building industry and research institutions have emerged.[2] The collaborations between companies and researchers show the possibilities for reducing energy consumption in buildings if they are carefully designed, however, the research also shows evidence of problems in handling new workflows and procedures in the design process2. These problems are also a focus in educational settings where, for example, Problem Based Learning (PBL) can be seen as one approach to teaching students about the complexities in the design process from the very beginning.[3]

In an educational context the buildings industry is still focused on developing the individual professions, such as architects, engineers and architectural technicians. The traditional subjects are still present in the curricula, but where the focus previously were on the use of AutoCad or other CAD programs, it is now on Building Information Modeling (BIM) software like Revit or MicroStation and—specifically within architecture—also on the computational and parametric dimensions of the design process, thus to some extent moving away from the “drawing board” towards understanding more about the design process. However, because the focus is mostly on the individual professions of the field, it leaves the question of how to use the different digital tools in a multi-disciplinary context where workflows and procedures should secure the exchange of information between the different professions.

Examples on multi-disciplinary design processes are occasionally seen in educational settings. One example is "De Digitale Dage" (DDD). DDD is a collaboration between Aalborg University, UCN, Tech College and SmartCity, where architects, engineers, architectural technicians and various craftsmen are involved in a three day workshop focusing on developing a project in multidisciplinary groups.[4] Another example is courses at Roger Williams University where a setup is made to simulate a "real world" project.[5]

Present paper takes its point of departure in how knowledge from different professional fields can be used to inform the design process in an interdisciplinary educational program. It discusses two different approaches to the design process used among students working with an integrated design process, where they focus on energy-efficient architecture and informing the design process with knowledge from the engineering and the architectural world.

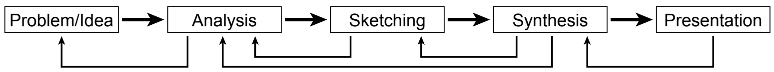
BACKGROUND

During the past decades, the focus on sustainable architecture has led to a discussion about how to work with an integrated design process. An example of an integrated design process is the International Energy Agencies Task 23.[6] Furthermore, terms like integrated energy design or integrated project delivery has emerged as terms describing a holistic approach to developing projects.[7] Evidence from studies of the design process in multi-disciplinary teams has identified a range of specific steps the design team progresses through, moving from the understanding of the problem to a final concept.[8]

Theory related to the design process suggests that architects base their designs on conjectures.[9] Furthermore, this theory is supported by evidence that shows that key parameters are selected to drive the conjectures.[10] Evidence from educational settings shows that students of architecture are taught a solution based approach similar to the conjecture based one seen in the architectural offices.[11] Thus, the focus is not on understanding the core problem of designing, for example, carbon neutral buildings and which buttons to push to succeed, but on designing a solution that fulfils the demands set up in the assignment or building program. Though the focus is primarily on a solution based model, different approaches are utilized in architectural educational programs.[12]

Teaching integrated design has been practiced for some time around the world. At Aalborg University, Denmark, where integrated design has been used to form the curricula for the past decade, both architects and engineers are used in the teaching of students based on the PBL model. Roger Williams University offers courses on the integration of the disciplines which focus on the integration of environmental simulations. Furthermore, research groups in academia focus on the topic of integrated design as a prerequisite for successfully fulfilling the increased demands on today's buildings, as it is seen at, for example, "IDBE" at Cambridge University or the "Interdisciplinary Laboratory of Performance - Integrated Design" at École Polytechnique Féderale de Lausanne.

With the focus on the process as shown above there is also the question of how it is realized. A key part of the discussion has for some time been BIM as a platform that can help to integrate the information from different professions involved in the design process, thus ensuring a coherent workflow and information flow.[13,14] In relation to green Architecture and subsequently carbon neutral architecture, experience shows that a range of different programs are needed and that they do not necessarily all belong to a BIM platform.[15] But talking about integration of



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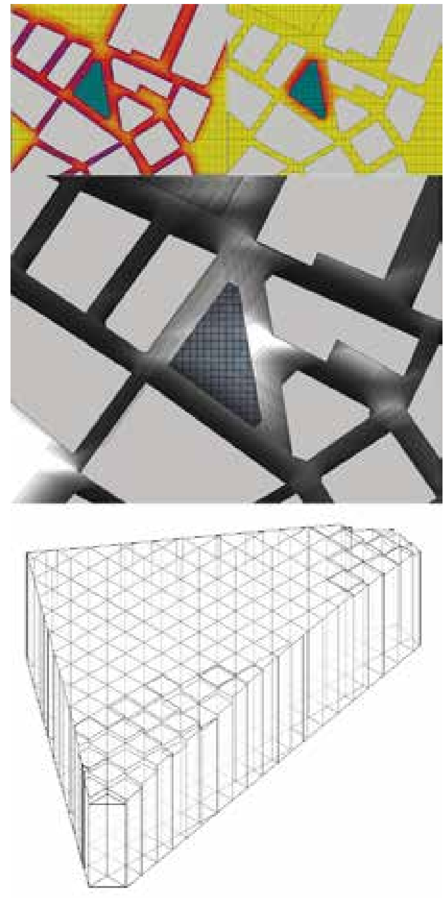
parameters also points towards more parametric approaches as used by, among others, Foster + Partners and Mark Burry, who have explored the potential in various projects.[16,17] Similar automation is seen in relation to algorithmic architectures, where the architect does not design the building but the procedure the computer follows.[18]



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METHODS

Present paper is based on observations made during supervision of students, as well as material from students' project reports and presentations. The three projects used here address issues about low-energy architecture and how knowledge about parameters that help affect the passive performance of the building can be integrated in the design process.

The three projects are analysed according to how the different steps in the design process are approached, which tools are used and the level of automation in the different steps. With this point of departure, it is discussed which possibilities are inherent in the workflows and procedures.

Though the focus is on low-energy architecture, the projects used here are not aiming at carbon neutrality, but the approach they use is relevant because it accommodates a larger range of parameters.

RESULTS

In the three projects used as examples, two different approaches were identified. In one of the projects (project 1), the focus is on exploring the possibilities of using BIM in the design process with primary focus on Revit and Ecotect, whereas the other two projects (project 2 and Project 3) focus on a parametric approach to the design process and how to utilize different scripts and parametric software to explore how different parameters can inform the design process.

Overall, the projects follow the same structure in an integrated design process, thus integrating the engineering dimension into the design process from the very beginning. In all three cases the focus is on low-energy architecture and the primary parameters are volume to surface area ratio, solar insolation, insulation levels and window area and orientation. A diagrammatic representation of the overall structure can be seen in figure 1. The results will be presented in relation to the five stages, though with primary focus in the three middle stages.

The first step is to define the problem and maybe to present the first basic ideas to their respective problems. As the three projects are in three different semesters, the frame and the elaboration of the problem differ. Project 2 in the second semester of the master program has the most elaborate project statement where the main focus is on designing a zero energy housing complex. In the other two projects, the students define the framework themselves and.

A thorough analysis is made based on the topics outlined in the problem statement. The analysis encompasses a range of different aspects from the theoretical directions and evidence within the specific field, to case studies of similar buildings and analyses of climatic, physical, social and cultural contexts.

Project 1 is very systematic in its analysis of the climatic conditions and the possible impact it has on the design proposal. It goes through the different steps of

Figure 1: Figure showing a diagram of the Integrated Design Process and the different steps it follows. Especially the iterations are important here (Knudstrup 2004).

Figure 2: Project 1 where the student focused on a BIM based approach utilizing a range of BIM related software in the analysis, sketching and synthesis phase of the project. Images courtesey of Niels Thuesen.

shading studies, insolation, wind and volume studies to form the building mass as the point of departure. The studies are made in Ecotect and each step is made manually and is based on the student’s interpretation of the data.

Project 2 and Project 3 also have systematic studies of the climatic aspects. Project 2 has a very diagrammatic approach and uses Ecotect to develop programs that focus on a wind rose for the site and a sun diagram for the site to determine possible shading of that context. Project 3 works with similar issues, but instead of the wind rose applied in project 1 and 2, the wind is studied in the CFD module in Vasari.

For all the projects, this stage leads towards an elaboration of the problem-statement and the vision for the project.

In the sketching phase, the projects take different directions where Project 1 approaches the process at this stage in a very traditional manner. The volume studies are informed further by various other parameters. All steps are still manual, though, and the information is still interpreted by the student. Though there are numerous layers of information, it is still the functionality and the design of the spaces that are in focus. The possible interoperability with other programs when making simulations is not used to its full extent. At the end of the sketching phase, the student transfers the model to Revit to start developing a more coherent model for the later stages and verification later on. At this stage, the student also starts to test indoor climate in Ecotect, even though comparison with simulation software validated for use in Denmark shows differences between the results in the programs.

In Project 2 and Project 3, the parametric approach starts to be more elaborate and it is seen that parameters from both indoor climate and the energy consumption are in play.

In Project 2, the geometry of the window openings are in focus. A script was made to deal with the geometry. Furthermore, a script linked the rhino model to Excel spread sheets which were developed to assess a building’s energy consumption and max temperatures based on volumetric studies, and direct feedback to the model was established to help inform the decisions. Furthermore, a link to Ecotect was made to assess DF in the various steps. Though the steps in the process were manual, an automated feedback loop was established and in the end the different steps were evaluated based on both the quantitative feedback from spreadsheets and Ecotect, but also by evaluating the expression of the facade.

A similar approach was seen in project 3. But instead of the manual steps seen in Project 2, an evolutionary approach was utilized with Galapagos for Grasshopper. In connection with this, the work with daylight was not used until a solution had been found; as the DF was not an integrated part of the Grasshopper model. However, had there been problems with daylight tweaks would have been made in the original algorithm for the façade in order to meet the problems that had been encountered.

In the synthesis stage, all three projects start to gather the different solutions and ideas into a design that responds to the problem-statement and the vision. Here more detailed calculations and simulations of energy performance and indoor climate are made, and the work in this phase is more manual. For example dynamic simulations of indoor climate require that a new model is built in a simulation program. So whether it is a parametric approach or an approach based on a BIM

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Figure 3: Project 2 utilizing a parametric approach involving primarily Rhino and Grasshopper, however also scripting in Python. Furthermore linking to their own spreadsheets to direct feedback and studies in Ecotect. Images courtesey of Johan Kure, Kenn Clausen, Kemo Usto, Luke Lorimer Baylis and Thiry Manickam.

platform, it becomes a time consuming step. Especially if significant problems in the performance are found that require a rerun of previous steps.

It is also at this stage that the presentation material is starting to take form. Minor adjustments can also be made here in terms of selecting appropriate solutions for windows etc., which at earlier stages have been treated with relative descriptions.

The final stage is the presentation which in all these cases primarily focuses on presenting the final solution. In this case, the presentation is not that interesting.

DISCUSSION

The two different approaches to the design process identified in the results point in new directions of workflows and design processes, although the variety of parameters addressed and the scope of the studies in the three projects are limited. However, the question is to which extent the new directions respond to the emerging needs for new workflows and procedures in the design process.

The students' design processes cannot be considered significantly different from what has been seen before. Work focused on BIM has been seen before, although maybe using other programs. Using scripts and algorithms in the design process to describe relations in the geometry have also been seen before. However, the increased focus on calculations on energy from the beginning of the projects suggest a move towards better integration of energy performance in the design process, Thus, we can see a change in procedures and workflows that affect the design process. It is also evident that extensive knowledge is required to make full use of such methods. This has also been seen in previous studies where the implementation of environmental engineering in the design process is discussed.[19] In the three projects, the students use their knowledge about which parameters effect the energy consumption in order to run specific analyses, as an integrated part of the design and to run relevant simulations and calculations to inform their design process.

Furthermore, the interpretation of the results from the different steps is dependent on the, in this case the students' ability to understand how the different parameters affect the result in the given setup. In that respect the investigation of how different parameters affect the energy consumption is relevant as it can help to identify the parameters with the most impact, which points towards using sensitivity analyses.

Although the students in these projects address engineering as well as architectural issues themselves, the projects do not suggest limits to the need for the multi-disciplinary design team. On the contrary, they make the multi-disciplinary team even more important when trying to avoid misinterpretation of results as well as applying / gaining knowledge about the relevant parameters to use. In the three projects the students have been able to achieve this through their interdisciplinary approach and by addressing both the technical parts of engineering and considerations about the architecture and how the parameters relating to both fields are interrelated; however, in more complex projects with a larger number of parameters it quickly becomes more complex and more specific knowledge from the different professions could be beneficial. But from an educational point of view it is interesting that the students have the potential to work in a multi-disciplinary design team and mediate between the professions and implement the relevant knowledge into the different models to help create a more fluent workflow.

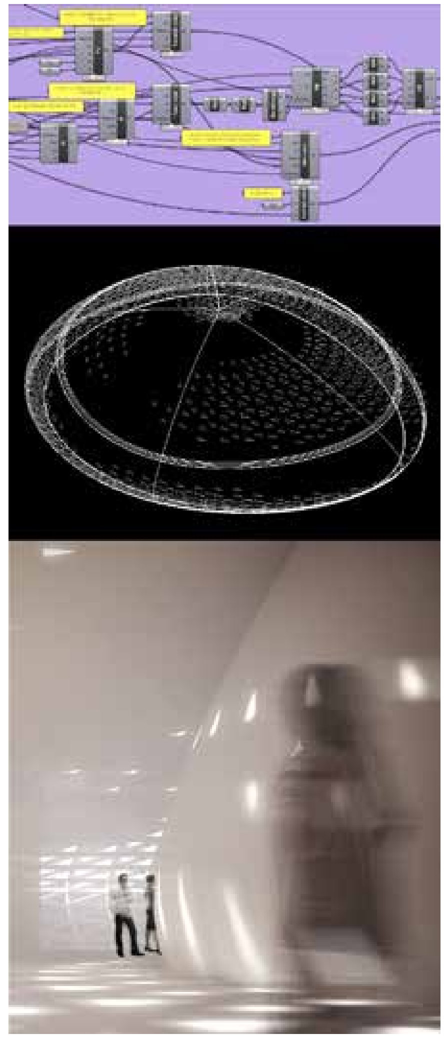

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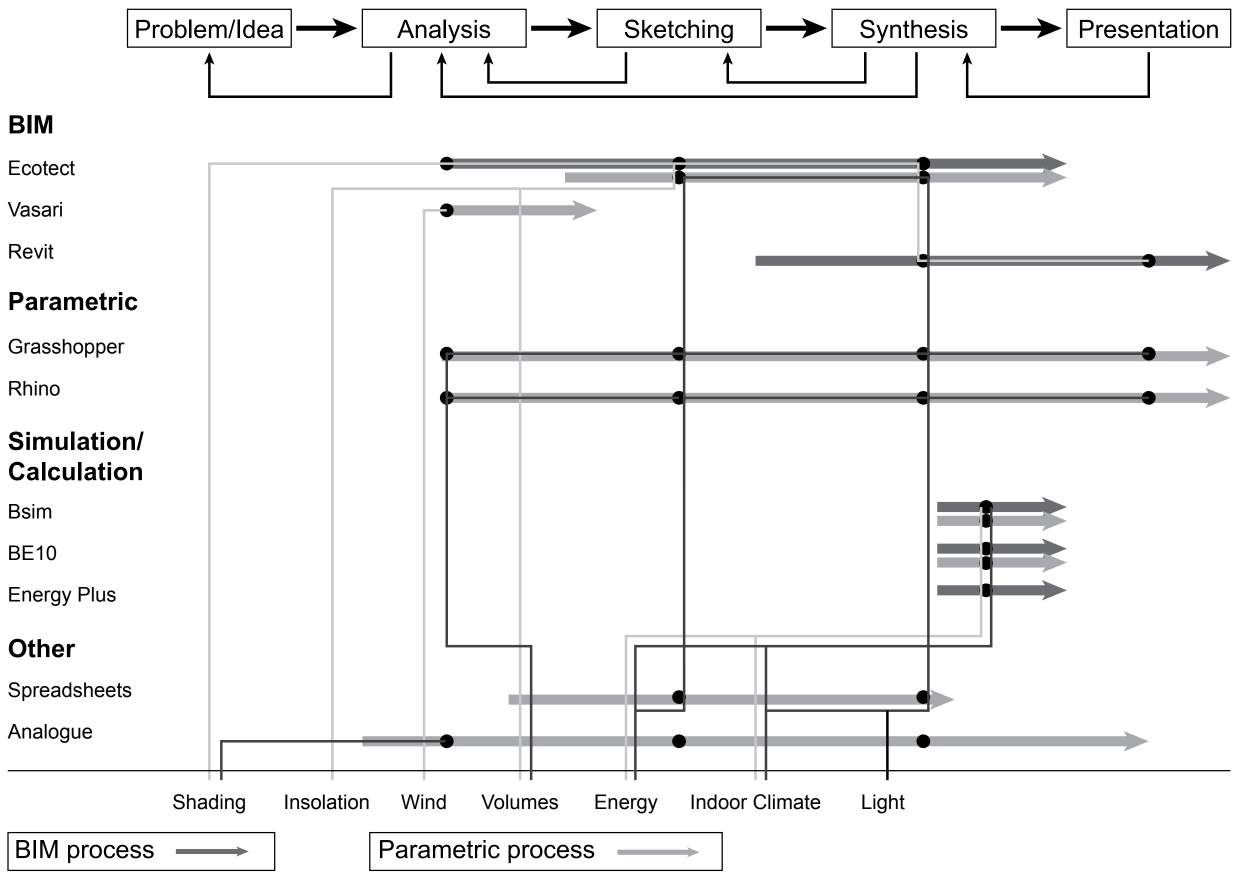
Figure 4: Project 3 using a parametric approach focused around Grasshopper and Galapagos to work with an evolutionary approach. All analyses are generated and assessed within Grasshopper, Images courtesy of Chenqi Jia.



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Of course, one could have wished for the projects to look into the manufacturing of the different parts, especially Project 2 and Project 3. By integrating such parameters in the design process, a step could have been taken towards assessing possibilities in the production and the erection of the building. Again, it is not a novel thing to do, as it is something that has already been seen in realized projects, as for example Foster + Partners.[17] The control of the manufacturing and construction process is also seen in Gehry's work where the use of software from the flight industry has allowed for more complex forms.[20] So, the work in the projects has close relations to the developments in practice and suggests how carbon neutral considerations can be integrated in the design process from the very beginning. Had the students been able to continue this work and address issues about for example integrating energy producing elements and optimizing materials based on environmental considerations as well as the construction process as seen from practice, the process could have closed the loop and could have addressed the broad spectrum of parameters that are highly relevant for working with carbon neutral buildings.

However, in the projects there are connections to the theoretical discussion seen as early as the seventies and the considerations about what possibilities the computer could bring to the architectural profession[21] and later the discussions about an evolutionary architecture.[22] Although the projects work with these issues on a very limited scale, they do show what the possibilities are. What is extremely important in these projects is that the students have selected specific parameters related to both the technical performance and the architectural expression to drive the process and then integrated evaluation of both the technical and the architectural in the design process. Furthermore, it is the students themselves

Figure 5: An overall representation of the two approaches to the integrated design process, based on which tools they use. Both approaches show the relative complexities in the interrelations, although a limited amount of parameters are being addressed.

that have driven the projects and explored the use of the tools in the design process. Thus, the project work becomes a valuable learning tool for them when learning about not just about the specific skills and competencies for this project, but also how to handle and implement new knowledge into the design process.[23]

All three projects show close relations to a traditional process based on conjectures. Furthermore, one can identify a primary driver in the projects, being the energy consumption or environmental concern, thus confirming the evidence found in previous research. However, in the analysis phase of the project, the solution space is quickly reduced based on the information from the various preliminary simulations and calculations. This is evident in both approaches. The workflow defined by the use of the digital tools and applications supports the process and suggests that it must be explored further in an educational setting in order to help drive the development towards carbon neutral buildings.

CONCLUSION

Present paper has discussed the application of various methodologies based on digital technologies in the design process among a limited number of students. The background for the design process applied by the students is an integrated design process based on a PBL approach. One of the projects are based on investigating how a BIM based approach is related to the integrated design usually taught in the architectural program, whereas the two last projects explore the application of parametric approaches based on Rhino. In all the projects, the focus has been on designing low-energy architecture. Throughout the process the students have worked with parameters related to both the technical performance assessed through simulations and calculations in the field of engineering, and the architectural expression. Even though the number of parameters used by the students in the design process is limited, it is evident that both BIM and parametric approaches have potential.

Through the projects it is seen that the implementation of automated processes has potential, but the projects also show the complexity in implementing such automation. The interrelationships between the parameters quickly become complex and the amount of data that needs to be evaluated and interpreted increases. So, a critical discussion about what is important in the individual project is a key to the implementation of the relevant approaches. Furthermore, it is important to ensure that the students have the knowledge needed to process the data and interpret into design solutions to benefit from the workflow they design.

The three projects used are different from what is usually encountered in the educational context. All the projects were driven by the students' curiosity towards exploring the digital tools and applications they found and the possible workflows and procedures they suggested. But the three projects show that linking the knowledge from the architectural field directly with the knowledge from the engineering field gives the possibility to get instant feedback and inform the design process. Furthermore, the projects show that parametric studies can be used for limited parts of the projects, as none of the projects work with fully parametric, algorithmic or computational processes nor do they deal with all the possible parameters, but different parameters could be introduced to address further issues in relation to carbon neutral buildings.

From an educational point of view this is also in line with a PBL model of teaching where the students' ability to both define and solve the problems is in focus.

ENDNOTES

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However, instead of applying a purely conjecture based approach to the design as it traditionally seen, the application of both BIM and parametric methodologies open up for the possibility analysing how to solve sub-problems without losing sight of the overall solution. Thus, it also allows the students to focus on exploring specific parts of the design of a building and on how different parameters are interrelated, though the interrelationsship between a parametric approach and a BIM approach is not explored by the students. In this case, energy consumption was in focus. However it could also have been an optimization of the structural framework to red uce the materials in the construction or the manufacturing process. So BIM and Parametric methodologies are not just tools to optimize the design process, but they can also be used pedagogical tools creating links between the design of the building and an understanding of which parameters in the design affects the performance of the building and in which way.